***Passing the Final Exam*:**
Commissioning HVAC Systems for High Performance Schools

by

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What is the Hazard or Problem:

Commissioning is improving the delivery and acceptance of new school construction and renovations projects. Acting on behalf of the owner (the City or Town), flaws in the building design and defects in construction can be identified and corrected early in the build cycle. In addition, there is a reduction in the change orders and claims, post-occupancy corrective work and operating costs.

The Solution:

Commissioning is the systematic, documented and collaborative process that evaluates the performance of your school and provides assurance to the School Department and the community that the new or renovated building operates as intended. Just as preparation for a final exam begins at the first class lesson with studying intensifying as the test day approaches, so to does the commissioning process work.

Successful commissioning projects provide trust and confidence in the design and construction team for the owner and the community in the acceptance of a new school.

The benefits of commissioning to the School Department and the community include:

- Early identification and correction of design defects
- Reduction in change orders and claims
- Reduction in project delays and shortened building turnover period
- Enforcement of approved operations and maintenance training start-up requirements
- Increased reliability and maintainability
- Reduction of post-occupancy corrective work
- Reduction in energy and operating costs with improved indoor air quality

Commissioning does not add to the overall cost of construction but actually serves as an insurance policy that creates the potential for significant savings of both construction-related and operating costs. Most commissioning projects show a simple payback period of hard cost savings of less than one year.

(continued on next page)

Applicable Regulations/Consensus Standards:

American Society of Heating, Refrigerating, and Air-Conditioning Engineers

Building Commissioning Association

US Green Building Council

Who in your Town or School Can Help:

Director of Buildings and Grounds

Town Architect

Who to contact for free Government or Other Assistance with the Problem:

Boston Society of Architects

Building Commissioning Association

Portland Energy Conservation

Department of Energy

Further Reading (include Electronic Resources if Applicable):

ASHRAE 1989. *ASHRAE Guideline 1-1989, Commissioning of HVAC Systems.* Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

Levin H. 1997. Commissioning: Life Cycle Design Perspective. *Proceedings of the Fifth National Conference on Building Commissioning.* Huntington Beach, CA. April 28-30. Portland, Oregon: Portland Energy Conservation, Inc.

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BUILDING COMMISSIONING FOR MECHANICAL SYSTEMS

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1. INTRODUCTION

The American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc. (ASHRAE) published its original guidance document on commissioning heating, ventilating, and air-conditioning (HVAC) systems in 1989 (ASHRAE 1989). The document presents a framework in which to view the commissioning process and general requirements that can be adapted to various projects. While this is still the most widely cited guideline on commissioning, many commissioning projects involve building systems beyond heating, ventilating, and air-conditioning. In this manner, a well-conceived commissioning program can serve as an overall quality assurance measure for integrating complex building systems. These additional building systems could include the building envelope, mechanical and electrical systems, power and communication systems, occupant transport systems, fire and life safety systems, water systems, specialized control areas, and building management systems.

Commissioning has been defined as a systematic, documented, collaborative process to assess the ability of a building and it's component systems to meet design intent and the needs of its occupants. This process begins in the design phase and should last at least a year after the completion of construction. Properly executed, the process includes the training of operating staff and ensuring through documented verification that all building systems perform interactively according to the design intent and the owner's operational needs (PECI 1996). Commissioning is most valuable when system performance is evaluated under the full range of load and climate conditions. The ability to assess system performance under part-load or extreme conditions is often the best way to discover problems in buildings and correct them before occupancy.

This process has proven so successful that several states are promising to include it in revisions to their codes. For example, Massachusetts will require specific construction documents that will include:

- Design Intent
- Basis of Design
- Sequence of Operation
- System Operation
- Testing
- Operations and Maintenance Manuals
- Record Drawings

Benefits

The value of commissioning projects is most often cited with respect to new building construction projects. Part of HVAC design intent is formally documenting performance objectives; basing the criteria of acceptability on these performance objectives, from construction through to system operation, results in a better functioning building. As useful as these procedures are for new construction, they can be equally valuable in renovation projects and energy conservation programs. Many times, the startup, control, and operational problems that occur due to "minor" changes made in localized areas can often compromise the performance or efficiency of entire buildings. Furthermore, when one considers the impact that HVAC systems that are deficient in operation can have on indoor air quality, the benefits of incorporating proper building commissioning activities in all HVAC-related projects is obvious.

The benefits that can be realized from a complete commissioning program include:

- Higher quality building systems and the knowledge that the facility operates in a manner consistent with the original design intent and meets occupant needs.

- Identification of system faults/discrepancies early in the construction process so that they can be resolved in a timely manner while appropriate contractual entities are still on the job. This will reduce the number of contractor callbacks.

- Improved documentation, training, and education for operators and facility managers to ensure longer equipment life and improved performance.

- Increased equipment reliability by discovering system problems during construction. In this way, commissioning prevents costly downtime due to premature equipment failure, as well as reducing the wear and tear on equipment by ensuring that the equipment operates properly.

- Reduced operation and maintenance costs.

- Improved occupant comfort and indoor air quality. Managing these factors effectively can reduce employee absenteeism and improve productivity and morale. Furthermore, the reduction in occupant complaints of discomfort minimizes service calls to building operators during the life of the building.

- Reduced potential for liability and litigation. This is true for both minimizing liability of owners due to occupant personal injury cases and minimizing litigation of engineers and contractors due to claims from owners.

Building owners who have had their buildings commissioned overwhelmingly cite energy savings and the assurance that systems will operate correctly as the important reasons. Figure 1 shows the results from follow-up interviews with owners involved in some 175 projects.

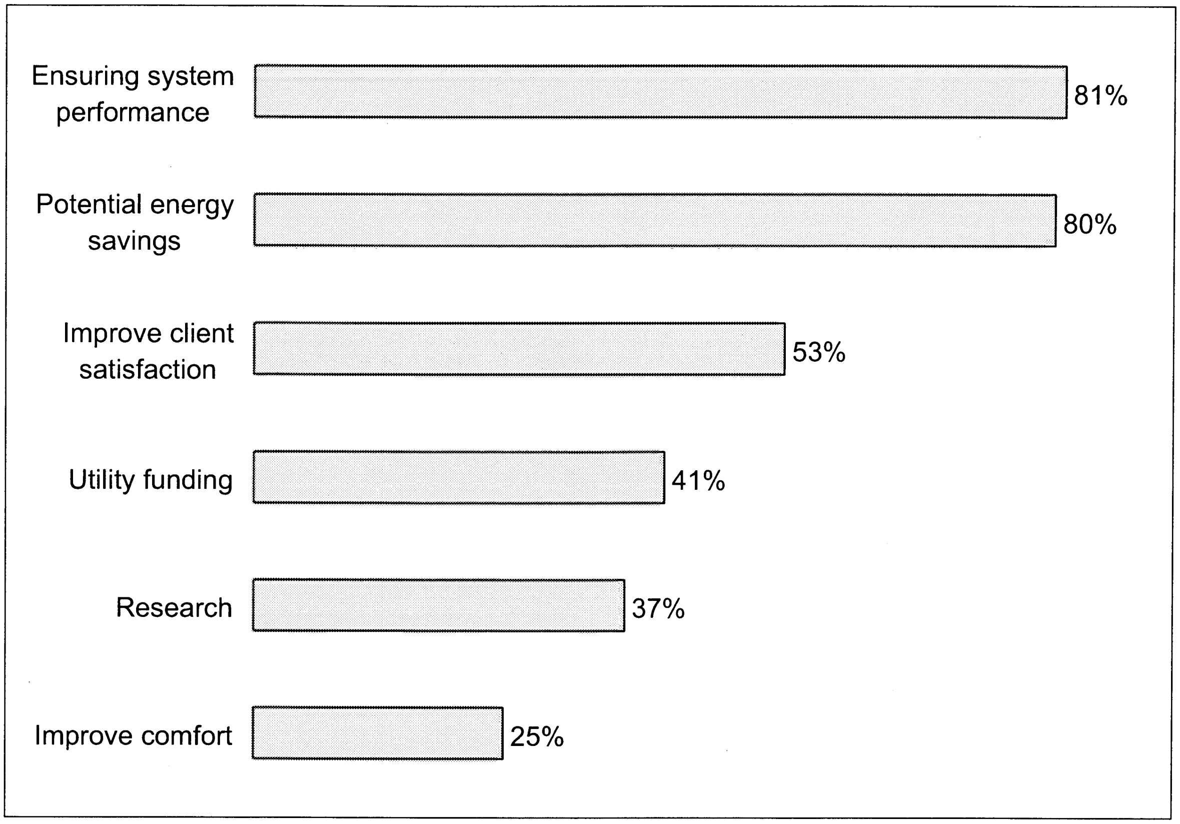

Figure 1 Why Owners Commission Their Buildings. (Copyright Portland Energy Conservation, Inc. Portland Oregon. Reprinted with permission)

Selection of a Commissioning Authority

Commissioning involves a variety of technical expertise, such as engineering, controls, and life safety, as well as the ability to assess interactions. It does not fall under the purview of any single discipline. Therefore, a separate commissioning agent, or as ASHRAE now prefers to designate the role, commissioning authority (CA), should be part of the project team and carry out these required evaluations and documentation. For this function to be effective, it is generally most appropriate that the CA be independent in nature and report directly back to the building owner.

The following section describes the various options that have been proposed to fill the role of CA and the pros and cons for using each one.

- *The owner.* The owner might appear to be an obvious choice for commissioning authority since he or she has a vested interest in ensuring the building is specified, constructed, and operated as envisioned. Utilizing in-house staff, the owner might control the commissioning process to ensure that the contractor delivers the building properly. Assigning staff to deal with commissioning, however, could delay construction and divert efforts from other projects. Staff might be conflicted between timely completion of a construction project and requiring modifications risking delays. In-house staff may lack the appropriate expertise to effectively serve as a CA.

- *An outside expert.* The owner can still act as a commissioning authority by hiring an outside expert to serve in the role of the CA. The expert would report directly to the owner on the contractor's performance and provide effective monitoring of the commissioning progress. This also requires that the outside consultant be given appropriate authority to coordinate outside subcontractors for the many commissioning activities that are required. For this program to be effective, the line of authority from the owner to the commissioning authority must be clearly defined.

- *General contractor.* It is logical that the contractor be held accountable for quality control, which takes into account many of the activities required for effective commissioning of a building. Furthermore, it is the general contractor who is responsible for construction sequencing and who should effectively police the quality of workmanship on the job. The general contractor has a stake in the successful completion and timely delivery of the entire project. There is also direct financial benefit if the general contractor can reduce warranty and service calls in the future. Of course, the major drawback is the possibility of a conflict of interest since the contractor would be responsible for replacing any items found to be deficient. To try to avoid this conflict of interest, owners should retain the prerogative of approving or disapproving the work of the general contractor as commissioning agent by performing spot checks and providing quality assurance of the contractor's commissioning efforts. However, by doing this, the owner may generate animosity and ill will since the exercising of this authority will directly undermine the activities of the general contractor as commissioning agent.

- *The engineer of record.* Advantages in using the design engineer as a commissioning agent include that fact that the engineer has full knowledge of the system design and is intimately familiar with its sequence of operation. This could be seen to achieve significant economies. However, there is a potential conflict of interest since the design engineer may not acknowledge problems that are in fact design errors since they would be his or her responsibility. Also, a major benefit of commissioning, that of outside peer review, is lost in this approach. Areas of design that could be deficient may not be captured since the engineer may not see them as deficient.

2. THE COMMISSIONING PROCESS

The commissioning process can be undertaken in phases which best start at the design phase and can be carried through to the occupation and operational phases of a building. Of course, much benefit can be gained by performing the functional performance tests on the systems before owner acceptance and occupancy. However, costs to rectify design deficiencies discovered at this point could be more costly to correct.

Phase I: Programming Review

The building/HVAC commissioning process begins by:

- Designating a CA
- Establishing the parameters for design and acceptance
- Designating the responsibilities of the various parties
- Delineating the documentation requirements for the entire project

The CA, design team, and owner review the building program and identify the information required for effective design and performance criteria for building acceptance.

Phase II: Design Review

The CA is often thought of as a quality control element of the design team. As such, the CA would be responsible to review and document discrepancies between architectural/HVAC design and specifications and the owner's building system performance criteria. As the design review proceeds, the CA would also be responsible to review proposed value engineering options for conformance to codes, occupant needs, and system optimization, and to provide an opinion regarding resulting limitations. Early in the design phase, the CA is responsible for preparing and distributing a commissioning plan that identifies the responsibilities of each of the key members of the team and the scheduling of commissioning activities and deliverables. This should be in sufficient detail so that the required submittals designate parties and instrumentation that will need to be present for each test. In addition, the master construction schedule should include the schedule of commissioning activities and link them with other construction activities.

The CA must ensure that the design team takes explicit responsibility to document the following items:

I. Design Criteria and Underlying Assumptions.

The design criteria should include all of the following environmental considerations:

- Thermal conditions
- Special loads
- Humidity
- Air quality design criteria
- Occupancy (hours and levels of activity)
- Pressurization and infiltration requirements
- Lighting
- Fire safety
- Noise
- Life safety
- Vibration
- Energy efficiency
- Total and outside air requirements
- Maintainability
- Code requirements and impact on design

II. Functional Performance Test Specifications for Mechanical Systems.

Test specifications are developed during the design phase and allow the design team to better anticipate the commissioning process requirements. These specifications are required at a minimum to:

- Describe the equipment or systems to be tested. The description of the HVAC system includes type, components, intended operation, capacity, temperature control, and sequences of operation.

- Identify the functions to be tested. Operation and performance data should include each seasonal mode, seasonal changeover, and part-load operational strategies as well as the design set points of the control systems with the range of permissible adjustments. Other items to be considered include the life safety modes of operation and any applicable energy conservation procedures.

- Define the conditions under which the test is to be performed. It is important to consider all possible operating modes, e.g., full and partial loads, and the extremes of operating temperatures and pressures. The documentation that will be provided to support this is critical for it will clearly show the completeness of the engineer's design.

- Specify acceptance criteria. It is essential that the acceptance criteria be presented in clear, unambiguous terms. Where possible, the acceptance criteria should be quantitative with accuracy and precision requirements consistent with the limitations of the equipment and system design.

Phase III: Construction Oversight

During the construction phase, the CA is responsible for on-site inspection of materials, workmanship, and installation of HVAC system and components, including pressure tests of piping and duct systems. The CA should also observe and/or independently audit testing, adjusting and balancing, and calibration of system components.

Other activities that an effective CA performs during the construction phase include: 1) review of warranty and retainage policies prior to construction, 2) obtaining copies of contractor's approved equipment submittal for review, 3) ensuring that effective construction containment techniques are used, and 4) documenting and reporting discrepancies for the owner.

Finally, it is essential that personnel who will be responsible for operating the completed system receive adequate training prior to system acceptance. This is best done during the construction phase. The CA should take responsibility to ensure that this training is provided by appropriate personnel (often equipment manufacturers through the design engineer) for the numerous components that make up the HVAC system.

Phase IV: Acceptance Phase

The Acceptance Phase should follow the commissioning plan established during the design phase. The functional performance test specification forms the basis for documenting the acceptability of the installed systems. The CA certifies performance either by conducting tests personally or by observing the appropriate parties testing the functional performance of each system. This testing should start at the lowest reasonable level, i.e., system components, then on to subsystems, then finally systems, until every piece of equipment has been tested. The CA must also ensure that all essential activities have valid performance tests (e.g., hydrostatic testing; testing, adjusting, and balancing work; and calibration of automatic controls) and that the tests have been completed to a satisfactory level prior to starting the acceptance verification procedures. As stated earlier, it is critical that testing is done in all modes of system operation, including full load and emergency conditions.

All required documentation should be compiled to form the basis of the system operations manual. Furthermore, as-built documents should be revised to ensure that accurate plans are available showing all relevant control points and values.

Prior to final acceptance, the CA will produce and distribute to the appropriate parties a document detailing all discovered deficiencies in the form of an action list. After required work has been completed, the CA will revisit the site and perform follow-up performance testing where required to verify that all action list items have been successfully resolved.

Phase V: Post-Acceptance Phase

The Post-Acceptance Phase can best be thought of as an ongoing audit function of the building systems and the building's occupancies. Periodic retesting, especially during the first year, is often advisable. This can be particularly important during extreme seasonal variations from the original commissioning period or during design extremes. The CA should also document the building operator's adjusted set points to ensure that they are consistent with original design. Where differences exist, the CA should evaluate the impact and reconcile them in a written report.

3. COST AND OFFSETS

There is currently no standard approach to costing commissioning services. Some of the more common methods are:

a) Budgeting a percentage of the total mechanical/electrical cost of a project. A range of 2.0 to 6.0% is generally considered reasonable, with the higher percentages generally being utilized for those projects that are smaller in scope or those that are more complex in nature.

b) Setting up a separate commissioning budget that is independent of the project budget. This is often useful in a case where the owner has an ongoing construction program, such as that found in many hospitals. Setting aside a commissioning budget that represents between $0.10 to $0.28 per square foot allows the work to be carried out over a number of projects over a year's time. Most owners utilize an operations budget although some do capitalize this work.

c) Utilizing a payment schedule based on time estimates provided by the CA to the owner. In these types of projects, it is important that all parties agree in writing as to what constitutes a completed plan, as well as an appropriate payment schedule.

No matter what budgeting approach is selected, it is imperative that contracts with the general and specialized contractors specify their financial liabilities. Although the CA is initially paid by the owner, additional charges incurred by the CA will be paid by the contractors if systems fail or cause delays to the schedules established for the commissioning.

Commissioning abuildi ng with the intent of improving performance can save owners and tenants tens of thousands of dollars over the operating life of the building. The Department of Design and Construction for the City of New York developed "High Performance Building Guidelines" in 1999, which included commissioning as an essential component. They are described as easy to implement requirements that can achieve 10% to 30% reductions in energy and water use while improving productivity. Commissioning agents today must inform their clients of these potential savings as listed in Table 1 and described in more detail in the NYC Department of Design and Construction 1999 report. Substantially greater savings are possible if the owner desires "green design" involving a systematic analysis of the HVAC demand, lighting, material content, recycling of waste, and water use, among other components. New guidance documents, such as the US Green Building Council's Leadership in Energy and Environmental Design (LEED™) program require commissioning of buildings to ensure optimum performance of installed system.

Table 1 Cost and Potential Savings Projected for NYC Buildings if High Performance Guidelines are Implemented

Facility or Service	Cost	Savings
Energy	$1.50 – 2.00/sq ft-yr	$0.30 – 0.80/sq ft-yr $70K for 100K sq ft
Water	$0.0025 – 0.0050/sq ft-yr	NYC could save $625K/yr if leaks were fixed
Waste	$40 – 100/ton	$0.17/sq ft-yr Recycling could capture $30 – 80/ton 10% recycling would save $3M/yr
Maintenance	$1.00 – 1.50/sq ft-yr	$0.11 – 0.77/sq ft-yr
Labor	$200 – 300/sq ft-yr $500 for medical safety personnel	1% increase in productivity $2 – 5/sq ft-yr $500K for 100K sq ft 1% reduction in absenteeism $1 – 2/sq ft-yr $100 – 200M/yr for NYC

Source: New York DDC. April 1999. *High Performance Building Guidelines*. New York: Department of Design and Construction.

Although commissioning is often seen as an added cost to a project, owners experienced with commissioning do not find an overall cost increase to construct buildings. The costs provided above compare favorably with several other cost parameters normally associated with building construction. For example, the 2 – 6% of M/E project cost compares favorably with the range of change orders and claims generally encountered on capital projects, which can typically range from 9 – 18%.

In addition to the benefits cited earlier, experience shows that an effective commissioning program can also:

- Reduce mechanical change orders and claims by 10 to 50%
- Provide significant energy savings in the first year of operation
- Reduce overall system maintenance costs during the first year in an amount comparable to or often exceeding the cost of the commissioning program.

Figure 2 demonstrates the payback period for various activities undertaken in typical commissioning projects.

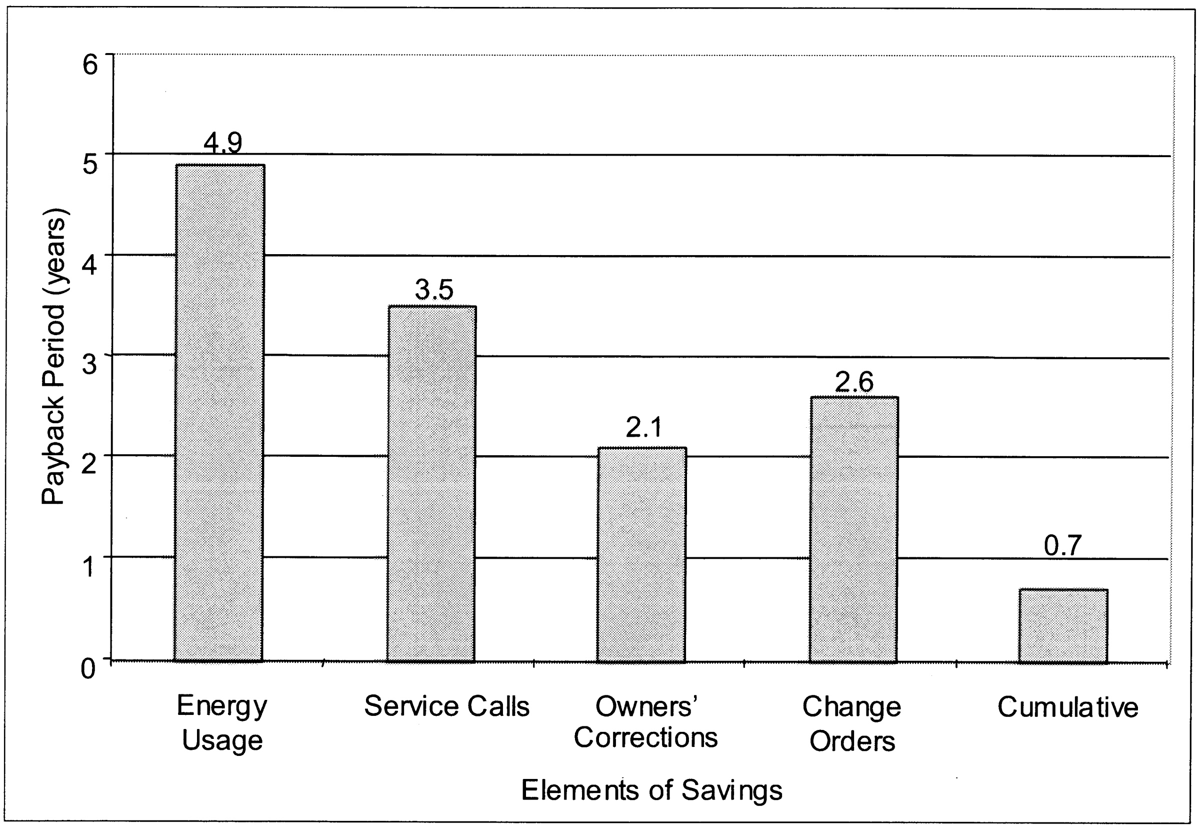

Figure 2 Payback Periods from Typical Projects

Levin (1997) lists the benefits reported by a Portland Energy Conservation, Inc., survey, including 146 case studies. The results are reproduced in Tables 2, 3, and 4. The data reported in these tables clearly indicate that commissioning programs provide important economic and operational benefits to the construction process.

While readily available data may not exist to demonstrate improvements in worker productivity, or illness rates due to commissioning activities, many groups have done extensive evaluation on the impact of commissioning and on implementing energy conservation or energy efficient measures. Piette (1996) studied the commissioning of energy conservation programs in 16 buildings in the Pacific Northwest and found that the investment in commissioning was cost-effective based on energy savings alone. Figure 3 shows the range of the present value of the total savings from commissioning compared to the cost of commissioning for each building. The range is based on the high and low lifetime value. These data clearly indicate that the benefits exceeded the costs, sometimes significantly, in the majority of cases.

Table 2 Benefits of Commissioning

Benefits of Commissioning	Percentage Reporting the Benefits
Energy savings*	82%
Thermal comfort	46%
Improved operation and maintenance	42%
Indoor air quality	25%
Improved occupant morale	8%
Improved productivity	8%
Reduced change orders	8%
Timely project completion	7%
Liability avoidance	6%

* >70% documented energy savings by metering or monitoring

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Table 3 Thermal Comfort Benefits of Commissioning

Benefit	Percentage Reporting the Benefit
Improved thermal control	90%
Reduced humidity control requirements	52%
Benefited from improved air balances	30%
Reduced occupant complaints	30%

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Table 4 Indoor Air Quality Benefits of Commissioning

Benefit	Percentage Reporting the Benefit
Improved ventilation	70%
Better contaminant control	22%
Improved carbon dioxide levels	19%
Improved moisture control	11%
Improved containment: cleanrooms or labs	8%

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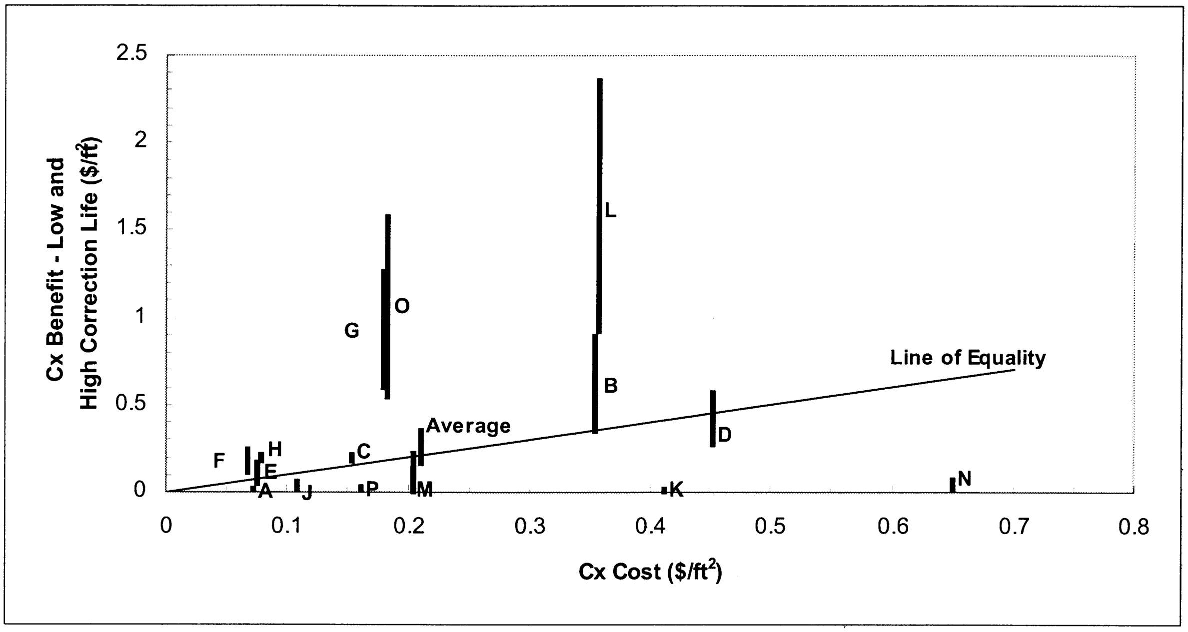

Figure 3 The savings from commissioning compared to the total cost of commissioning. *(Copyright American Society of Heating, refrigerating, and Air-Conditioning Engineers, Inc. From M. Piette and B. Nordman. 1996. Costs and benefits from utility-funded commissioning of energy efficient measures in 16 buildings. ASHRAE Trans. Vol. 102, Part 1. Reprinted with permission.)*

4. RECOMMISSIONING OF EXISTING BUILDINGS

There are many terms used to describe the process of getting occupied buildings back into optimal operation. All essentially use the process of auditing the functional performance of a facility and comparing it to some standard of acceptability. Recommissioning is viewed as a means to assure owners that their building still meets design intent and the acceptable performance standards that were detailed in the original occupancy commissioning document. Recommissioning can also serve as part of a quality assurance process to assure that the results of major renovations are still in conformance with the design intent of the original construction.

Recommissioning can also refer to the process of comparing the performance of previously uncommissioned buildings to an appropriate, newly established standard of acceptability (often called "retrocommissioning"). Alternatively, it can mean that a building's intended use has significantly changed and current building performance must be measured against other criteria of acceptability.

5. RECOMMISSIONING—A CASE IN POINT

An elementary school constructed in 1933 with 55 faculty members and 460 students was selected to undergo renovations to improve the performance of the building systems and the indoor environmental conditions. Work on the project began in the summer of 1997 continued through the summer of 1998.

What was found

Major environmental issues were discovered during the initial assessment of the school. Throughout the building, moisture control problems were evident. Water was entering the building through roof leaks and rotting windows, damaged steam pipes, faulty insulation, and cracks in the brickwork. This moisture intrusion had caused extensive mold growth on plaster walls, ceiling tiles, window frames, carpeting, and in ventilation ducts.

The ventilation systems were in a state of disrepair. Exhaust fans were inoperable, unit ventilators were not functioning properly, and control systems governing the central air handling units were faulty. The air conditioning system was broken and the boiler system was inadequate. Temperature fluctuations throughout the building were extreme. It was not uncommon for humidity levels to measure above 90%.

The school was infested with pests, including cockroaches, whose remains and fecal material were found in all areas of the building. Birds had nested in the soffit areas of the roof of the gymnasium and outdoor air intakes of the air handling systems.

Carpets were beyond restoration; they appeared moldy and discolored, damaged by water and excessive wear. In many places, the adhesive had loosened and the carpet had bubbled up, causing a tripping hazard.

Lead paint was found on window frames, doors, and banisters. Moisture damage was causing paint to peel off onto the floor.

Abandoned chemicals from unknown sources and unmarked containers in the basement mechanical room were leaking onto the floor.

What was done

232 windows were replaced to create a brighter, more healthful working environment, while keeping moisture out of the school. Lead paint was contained and removed. Brickwork was re-pointed and repaired where stress cracks caused water infiltration problems. The gymnasium roof was re-tarred and sealed. Portions of the slate roof were replaced, along with the flashings and gutters to better direct water. Water-damaged insulation was removed. Ductwork, steam and water pipes were replaced as needed to avoid further damage to building materials from mold growth and to prevent standing water that creates biological reservoirs. Other areas with visible mold damage, such as ceiling tiles and plaster walls were subdivided according to severity and location into high impact and low impact areas. Damaged building materials in high impact areas, such as classrooms and offices, were contained, treated with chemical agents, and removed. As a finishing touch, the entire school was repainted.

To improve ventilation in the building and to meet building codes, central fan systems were made functional with new belts. Fan motors were replaced as needed. Damper actuators and pneumatic control systems were replaced. Over 100 unit ventilators were made operational through electrical repairs, component replacements, and cleaning. The chiller was replaced, new boilers were purchased for heating, and exhaust systems were upgraded.

55-gallon drums of chemicals that had been abandoned in the basement rooms were removed as hazardous waste. The areas were decontaminated to eliminate residual chemical hazards.

Bird nesting was removed from the gymnasium roof area, outdoor air intakes, and exterior lighting fixtures. Several consecutive pesticide applications were used to reduce the extensive pest population. Then, Integrated Pest Management (IPM) measures were instituted, such as installing pest barriers and removing food and water sources.

What it cost and analysis

The preceding list of renovations merely suggests the magnitude of this project and the enormous costs associated with it. The following analysis dramatically demonstrates the costliness of such a reactive problem-solving approach—and the real value of a proactive approach.

- Spending on renovation in 1997 to repair damages attributable to poor maintenance of the two-pipe ventilation system: $1,508,405.
- Annual equivalent expenditures for 1997 renovation, discounted at ten-year treasury constant maturity rate to account for time value of money: $38,391.
- Annual spending on in-house maintenance required in order to avoid the need for 1997 renovation: $364.
- In other words, if the school had spent $364 per year on maintenance of the ventilation systems, it could have avoided the rehabilitation cost of $1,508,405.

6. CONCLUSION

Commissioning is a systematic and detailed process that requires the mutual commitment of the owner, contractors, and commissioning authority to ensure its success. The goal of commissioning is to turn over to the owner a building that meets the design intent with the appropriate safeguards (such as operator training and required documentation) to ensure that it will continue to function properly. As owners, contractors, architects, and engineers have begun to see the benefits of commissioning, they are incorporating it into their building projects. Although there are many definitions of commissioning, it is important to bear in mind that this is the ultimate quality assurance program in the life of a building. As such, it must clearly and unequivocally set the standards of acceptability. The commissioning authority has a responsibility to the owner and to the community of professionals involved in the building process to ensure that the highest standards are met and to ensure that a building performs according to its design intent and its occupant needs.

7. REFERENCES

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